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The Composition and Properties of Squid Meat

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ABSTRACT

Many European and American fisheries have recently started to exploit oceanic and inshore squid resources. There is thus a need for developing domestic markets for squid products. The yield of edible parts of squid is 60–80% of the total weight and the chemical composition of the meat is similar to that of lean fish. However, the structure of the muscles is different, being composed of several layers of fibres running transversally to each other and covered with several sheets of connective tissue. A characteristic feature of squid proteins is a high proteinase activity and high solubility of the myofibrillar proteins during exhaustive extraction with water. The cooking loss in squid is up to about 40%. The texture, which does not resemble that of cooked fish, and the juiciness of the squid mantle, can be controlled by the cooking time and by pretreatment in polyphosphate solutions.

INTRODUCTION

During the past decade the total yearly landings of marine fish and invertebrates have oscillated around 72 million metric tons. The resources of most valuable species are almost overfished but considerable possibilities of increasing the catch exist after intensifying the squid fisheries. Currently, the total world landings of cephalopods constitute only a few per cent of the potentially available resources.

Traditionally, squid fisheries have been operating on a large scale in

Japan, in the Southeast Asian countries and in southern Europe but, since the end of the nineteen-seventies, American, New Zealand, Canadian, Soviet and Polish fishermen have also participated in exploiting cephalopod resources, mainly for export purposes. As the international trade in cephalopods is significantly influenced by the fluctuating yearly landings and by the cold storage holdings, developing a demanding domestic market for squid products should be of economic advantage for many European countries. To achieve this end it is necessary to learn more about the properties of squid meat as raw material for products acceptable to the unaccustomed palate.

AVAILABILITY

Squid resources, in large enough concentrations to sustain commercial fisheries, are abundant mainly within the 200 mile economic zones,

TABLE 1
The Mainly Exploited Species of Oceanic Squid (Kreuzer, 1984)

Species	*Maximum mantle length (cm)*	*Distribution*	*Properties and utilization*
Todarodes pacificus	50	North Pacific	High eating quality, used as 'sashimi' and dried, high commercial value
Ommastrephes bartrami	50	Temperate and tropical oceans	Meat more tough than that of *T. pacificus*, high commercial value
Nototodarus sloani	42	Southwest Pacific, eastern part of the Indian Ocean	High eating quality and commercial value
Todarodes sagittatus	75	European and African Atlantic waters, Mediterranean Sea	Used for food and bait
Illex illecebrosus	31	North Atlantic	Used for food, high commercial value
Illex argentinus	35	Southwestern Atlantic	Used for food, high commercial value
Dosidicus gigas	150	Pacific from southern California to southern Chile	High eating quality, important for the local fisheries

although various species inhabiting the oceanic waters are also known. Recognized squid fishing grounds in the Atlantic are mainly on the shelf off North America, in the Gulf of Mexico, in the Carribean Sea, on the Patagonian shelf and along the European shore. Limited resources, of value for the local fisheries, are also in the Mediterranean Sea. In the Pacific, large concentrations of squid have been found in the near shore waters from British Columbia to Mexico, as well as along the coast of Japan, in the Yellow Sea, in the South China Sea and in the 200-mile zone off New Zealand and Australia. There are also known resources of oceanic squid in the Pacific.

For commercial fisheries several species of two large families of squid are most important, the Ommastrephidae (Table 1) and the Loliginidae (Table 2). The total number of known species is 270. The *Loligo* species are generally regarded on the world market as more valuable. The catches of the Polish vessels are composed mainly of *Illex argentinus*, belonging to the Ommastrephidae family, and of *Loligo patagonica*. The total Polish yearly catch of squid is about 120 000 tons. Most of it is for export as the

TABLE 2
The Mainly Exploited Species of Inshore Squid (Kreuzer, 1984)

Species	*Maximum mantle length (cm)*	*Distribution*	*Properties and utilization*
Loligo vulgaris	42	Warm Atlantic shelf of Europe and Africa, Mediterranean Sea	Excellent sensory properties, sold as fresh, high commercial value
L. forbesi	90	Cold European Atlantic waters	Important for some local fisheries
L. pealei	50	North American Atlantic coast	High eating quality, important for the American and European fisheries
L. opalescens	19	North American Pacific coast	Sold as fresh, dried and canned, important for the local fisheries
L. edulis	40	Asian coast of the Indian Ocean, Sea of Japan	Excellent sensory properties, used as 'sashimi', high commercial value

demand of the domestic market in 1983 did not exceed 1000 tons of squid products.

The fishing efficiency achieved by using jiggers, i.e. special kinds of hooks on lines, is of the order of 200 specimens per hour from a 40 m line. Although less efficient than seining, jigging is better for the quality of the landed squid.

THE STRUCTURE AND GROSS COMPOSITION OF SQUID FLESH

There are species of very small squid, with a mantle of only a few centimetres long, as well as giant squid, reaching several metres. The *Illex argentinus* landed by the Polish fishermen is graded into three sizes—small, 18–23 cm of mantle length; medium, 23–28 cm, and large, more than 28 cm. The respective classes for *Loligo patagonica* are: less than 10 cm and greater than 15 cm.

The yield of edible fleshy parts in the body of squid (Fig. 1) is exceptionally high, being 60 % to 80 % of the total weight, depending on the species, the size of the specimen and the sexual maturity.

The muscles of the squid mantle differ in structure from the muscles of fish and mammals. They are composed of several layers of fibres running transversally to each other and covered with several sheets of connective tissue. According to the recent findings of Otwell & Giddings (1980) the

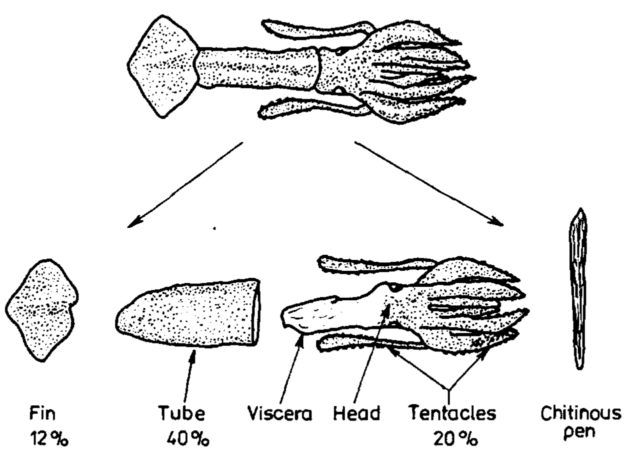

Fig. 1. The yield of the edible parts in squid.

muscle fibre layer of the mantle of *Loligo pealei* makes up about 98 % of the mantle thickness. It consists of 0·1–0·2 mm thick bands of fibres running circumferentially, which are sandwiched between thinner sheets of radial fibres. The composed layer of muscle fibres is covered by four sheets of connective tissue: the inner tunic and the visceral lining on the side of the body cavity and the outer tunic and outer lining under the skin.

Just under the skin proper there are pigment cells containing dark red and brown melanin compounds. Skinning of very fresh squid removes these pigment cells, together with the skin. The flesh of such skinned squid is milky white. After several days in ice the membranes of the pigment cells rupture due to autolytic processes and the pigments cause reddening of the meat. Further changes in the pigments due to heating may bring about severe darkening of the product.

The gross chemical composition of the meat of squid mantle and tentacles is similar to that of lean fish. The meat contains 75–84 % of water, 13–22 % crude protein, 0·1–2·7 % lipids and 0·9–1·9 % minerals. The nitrogenous compounds include, as well as proteins, about 37 % of non-proteinaceous components. This fraction consists mainly of trimethylamine oxide (TMAO), 300–1300 mg/100g, and the products of its metabolism, other amines, free amino acids, chiefly octopine, 450–1150 mg/100 g, arginine, up to about 600 mg/100 g, glycine and alanine, and of betains and nucleotides. The lipids of squid mantle are usually phospholipids and contain about 4 % of cholesterol. The fatty acid composition of squid mantle lipids has been found by several investigators to be similar to that of the flesh lipids of lean fish. According to Hayashi & Takagi (1979), in the lipids of four species of squid the saturated fatty acids range from 21 % to 33·1 %, the monoenoics from 8 % to 12·2 % and the polyenoics from 57·8 % to 70·7 %. The contents of

TABLE 3
The Contents of Elements in the Meat of Mixed Species of Squid
(Gajewska & Nabrzyski, 1979; Sidwell *et al.*, 1977, 1978*a*)

mg/100 g		*mg/100 g*		*μg/100 g*	
P	153–420	Fe	0·5–18·8	Mn	20–80
K	246–313	Zn	0·8–8·4	Hg	1–30
Na	176	Cu	0·2–1·6	I	20
Ca	10–109	Cd	0·01–0·5	Pb	0·7–16
Mg	20				

TABLE 4
The Contents of Vitamins (μg/100 g) on the Meat of Mixed Species of Squid (Sidwell *et al.*, 1978*b*; Wituszyńska *et al.*, 1979)

Ascorbic acid	4900	Pyridoxine	70–1300
Thiamin	8–201	Folic acid	12·5
Riboflavin	50–836	Vitamin B_{12}	1·3–13·0
Niacin	1·2–5·6	Pantothenic acid	680

branched chain fatty acids do not exceed 0·3%. The available published information on the composition of the minerals and vitamins in squid meat is very limited. As the results are highly influenced by the seasonal and biological factors, as well as by the handling of the samples, they must be regarded only as a rough estimate of values that can be expected in squid edible parts (Tables 3 and 4).

THE PROTEINS OF SQUID MEAT

The contents of the three main fractions of muscle proteins in squid mantle and tentacles differ slightly from that in fish muscles (Table 5). The sarcoplasmic proteins make up only about 15% of the total, while collagen constitutes, according to our data, from about 3% of the true proteins in the mantle of *Loligo* to about 16% in the tentacles of *Illex*, as

TABLE 5
The Protein and Non-Protein Nitrogen in Squid Meat (Kolodziejska, 1985)

Species and body part	*Total protein nitrogen (g N/100 g)*	*Protein fractions' nitrogen in total protein (%)*			*Non-protein N in total nitrogen (%)*
		Myofibrillar	*Sarcoplasmic*	*Collagen*	
Illex, tentacles	1·95	64·8	15·2	16·0	38·8
Illex, mantle	2·01	74·6	11·5	11·1	38·1
Loligo, mantle	1·85	79·0	14·9	3·0	36·2

All data represent mean values of results obtained by analysing four samples taken from one batch of mince prepared from the meat of several squid. The standard deviation for the Kjeldahl nitrogen does not exceed 1·5% and that for hydroxyproline, 9%.

calculated from the contents of hydroxyproline. A considerably high proportion of collagen in squid meat could be expected, taking into consideration the structure of the muscles and their rheological properties.

A characteristic feature of the sarcoplasmic fraction is a high activity of proteinases which brings about extensive degradation of the myofibrillar proteins in the course of fractionation. This degradation of myosin was, however, reported only in fresh, unfrozen muscle (Tsuchiya *et al.*, 1978). The proteolytic activity in squid muscles seems to be caused mainly by cathepsins D (Sakai & Matsumoto, 1981; Kołodziejska, 1985). The autoproteolytic activity in homogenates of frozen *Illex argentinus* at pH 3 is about 50 % lower than that in fresh *Ommastrephes* found by Sakai & Matsumoto (1981). However, according to Stanley & Hultin (1984*b*) in fresh *Illex illecebrosus* the autoproteolytic activity at pH 3 is five times lower than in fresh *Ommastrephes* but is still several times higher than that in the muscles of flounder and hake (Stanley & Hultin, 1984*b*). There are also indications (Rodger *et al.*, 1984) that squid muscles contain proteinases, active at slightly alkaline pH, which have maximum activity at 60 °C. Such enzymes are known to participate in texture changes in Japanese type fish pastes. The production of dimethylamine in frozen stored squid reported by Stanley & Hultin (1984*a*) may indicate the presence of TMAO demethylase in the sarcoplasmic fraction.

The components of the sarcoplasmic fraction from frozen squid were separated into twenty distinct bands using SDS PAG electrophoresis. These electrophoretic patterns were, however, more influenced by the freshness of the squid prior to freezing than by the species of the animal and thus could not be used for species identification of skinned mantle tubes (Kolodziejska, 1985).

The myofibrillar proteins of squid differ from those of fish and mammals by being more water soluble. Up to 85 % of the total protein in squid muscle can be solubilized with distilled water by exhaustive extraction (Matsumoto, 1959). Squid myosin was also reported to be more susceptible to trypsin and the myosin ATP-ase was more easily inactivated by heating than the myosin of fish and mammals (Tsuchiya *et al.*, 1978; Kimura *et al.*, 1980).

Paramyosin, the characteristic component of invertebrate muscles, makes up about 14 % of squid myofibrillar proteins (Horie *et al.*, 1975). According to Iguchi *et al.* (1981) it may be involved in decreasing the rate of protein denaturation in frozen stored squid.

The collagen in the muscles and skin of squid contains, according to various published data, about twice as many hydroxyproline residues per 1000 residues as the cod skin collagen (Sikorski *et al.*, 1984). Different samples of collagen, prepared by exhaustive selective extraction from the mantles, skin and muscle connective tissue membranes of frozen *Loligo* and *Illex*, contain, in dry matter, according to Sadowska & Sikorski (in press), 0·3–4·9 %, 3·5–6·1 % and 4·7–8·0 % hydroxyproline, respectively. Results of other work by the same authors indicate that the collagens in squid of different species differ in their crosslinking, as determined by the number of bonds susceptible to hydroxylamine, as well as in solubility in salt solutions and buffers (Sadowska & Sikorski, in press).

THE COOKING CHANGES IN SQUID MEAT

According to published data (Otwell & Hamann, 1979), cooked squid meat shrinks by about 30 %. Prolonged storage of the raw material in ice increases the shrinking loss while very fresh squid shrinks less. The cooking loss in weight is 25 %–42 % and takes place mainly in the first 15 min of heating (Fig. 2).

The hardness of the mantle decreases, according to our experience, continuously during cooking in boiling 2 % NaCl solution up to at least 60 min (Kolodziejska *et al.*, 1985). Other published data indicate that significant changes in texture take place only during the first 8 min of cooking (Stanley & Hultin, 1982). The shear value of *Illex* mantle after 1

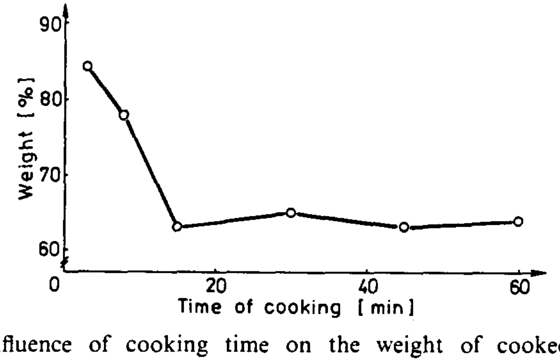

Fig. 2. The influence of cooking time on the weight of cooked squid mantle (Kolodziejska *et al.*, 1985). The time of cooking was measured from the moment when the cooking solution started to boil.

year of storage at $-20\,^{\circ}C$, cooked for 45 min, is 1·8–5·0 N and is significantly higher when sheared across the circumferential fibres than parallel to these fibres (Kolodziejska *et al.*, 1985). According to Stanley & Hultin, 1982; 1984*a*) frozen storage brings about a slight increase in hardness, although there is no distinct correlation between the texture of the stored meat and the concentration of formaldehyde formed by demethylation of TMAO.

The results of electron microscopic observations of the changes in the structure of different components of the squid mantle due to heating indicate that degradation of these structures takes place after a few minutes in a temperature range from 50 to 100 °C (Otwell & Hamann, 1979). However, even after 45 min of boiling the outer lining of the mantle can be still distinguished visually and can influence the texture of the product.

The sensory quality of cooked squid depends significantly on the characteristics of the raw material and on the conditioning of the mantles before cooking. There are some indications that the cooked meat of small specimens is slightly less tough than that of large animals. The state of freshness prior to freezing has, apparently, a very considerable influence on the texture of the squid meat cooked after prolonged frozen storage. Samples of *Illex* showing distinct discolourations of the skin and of the muscle layer just under the skin were found in our experiments to be about 30% less tough than more fresh, undiscoloured muscle (Kolodziejska, 1985). Holding of the meat prior to cooking during 18 h at room temperature or 2 h at 35 °C did not improve the texture of the cooked product, although it caused significant proteolysis of myosin, as shown by SDS-PAG electrophoresis (Kolodziejska *et al.*, 1985).

Curing in 2% acetic acid solution, although it brings about detectable proteolytic changes, considerably increases the hardness and adds a slight sour and bitter note to the taste of the cooked meat (Kolodziejska *et al.*, 1985). This increase in toughness can probably be explained by the fact that the pH of the meat after 1 day of curing is about 4·5, i.e. very close to the point of minimum water-holding capacity. The cooking loss in the cured samples is about 70% larger than that in controls; the meat is less juicy and tends to break during handling after cooking. By adding 1·5% NaCl to the curing solution the increase in hardness can be diminished.

Soaking the mantle for 15 to 17 h in 5% NaCl solution slightly decreases the hardness, while treatment with NaCl + polyphosphates

TABLE 6
The Hardness of Squid Meat Conditioned 16 h in NaCl and Polyphosphate Solutions at 2 °C (Kolodziejska *et al.*, 1985)

Conditioning solution	*Shear force N Shearing in respect to circumferential fibres*		*Cooking loss (%)*	*pH before cooking*
	Across	*Parallel*		
[1]	1·8–5·0 100 %	0·8–2·0 100 %	31 ± 7	6·6 ± 0·1
1 % Hamine[2]	73 ± 13	79 ± 15	20 ± 3	6·9 ± 0·2
2 % Hamine[2]	42 ± 20	62 ± 13	15 ± 3	7·1 ± 0·1
3 % Hamine[2]	39 ± 10	55 ± 10	9 ± 6	7·2 ± 0·1
3 % Hamine[1] + 5 % NaCl	58 ± 14	60 ± 14	19 ± 7	6·8 ± 0·1

The results represent mean values obtained in nine experiments (superscript 1) and three experiments (superscript 2). Within each experiment the shear value was measured on five samples from one squid.

(Hamine D) (a proprietary polyphosphate mixture, Waessen-Schoemaker, Deventer, Holland) or only with polyphosphates significantly decreases the toughness and cooking loss (Table 6). No effect of such treatments on the proteolytic activity in the squid meat was observed.

Addition of 0·2 % ascorbic acid to the NaCl cure influences neither the texture nor the yield of the cooked squid mantles. No differences in texture and yield were found between samples cooked in water or in 2 % NaCl solution.

CONCLUDING REMARKS

Of a large number of existing species of squid only a few are being exploited commercially. Of course, various squid species do differ both in chemical composition and in many sensory properties. The available published information on the chemistry of squid meat, the changes in the main components and the sensory properties of the cooked products are very limited. The same applies also to the rheological characteristics of the cooked meat. Many valuable research results pertaining to specific

Japanese squid products cannot be utilized in development work for the unaccustomed European market. According to our experience the texture of differently cooked squid mantles can resemble that of a hard boiled egg or, in some cases, even that of cooked beef meat. There is no unanimous preference of taste panel members, not accustomed traditionally to eating squid dishes, for either of these different textures. In order to enable the processor to control the flavour, juiciness and texture of the commercially cooked squid of different intial properties, it is necessary to learn more about the influence of the proteolytic enzymes, pH, salts and temperature on the changes in the main components of the squid meat.

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